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AUTHOR(S): J. Douglas Balcomb

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**LOS ALAMOS SCIENTIFIC LABORATORY**

Post Office Box 1663 Los Alamos, New Mexico 87545

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## STATE OF THE ART IN PASSIVE SOLAR HEATING\*

Los Alamos National Laboratory  
Los Alamos, New Mexico 87545

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J. Douglas Balcomb

### ABSTRACT

Passive solar heating has been demonstrated to be a cost effective, practical, and a widely acceptable approach to reducing energy consumption of buildings in virtually every US climate. Passive solar and hybrid technologies have the potential to replace up to 1.5 quads of energy annually by the year 2000, using conservative assumptions, and to stimulate small business growth and create employment opportunities in nearly every part of the nation. Mathematical computer analysis is the critical link tying key elements of the R&D program together and provides the basis for design tool development; data from test rooms and monitored buildings form the basis of model validation. Even though awareness of passive solar is high, and even though a variety of passive buildings types are being built in large numbers in many places, and even though 20 or more major design firms now specialize in passive solar, the practice is lagging far behind the potential. The confidence necessary for a major shift to passive solar has not yet developed. Examples of poor design as well as good design can often be found. Simple and inexpensive monitoring systems do not exist nor does a commonly accepted basis of comparison, understandable and usable by a prospective builder or buyer. First generation design tools suitable for simple configurations are in general use but designers of larger and more complex buildings are not so well off. Some effective new products and materials have been developed. Much work remains to be done.

### STATE OF THE ART

The state of the art is outlined below according to four major categories.

#### 1. Passive Solar Practice

The modern era of passive solar heated buildings has shown a remarkable rate of growth from a handful of notable examples built in 1960's and the early 1970's to several tens of thousands today.

Awareness. Virtually unknown and only given a name in 1967, passive solar has quickly reached a nearly complete state of awareness within the housing industry and a high level of awareness among prospective and existing building owners. This is due to solar organizations, to professionals practicing in the field, to educational campaigns by federal and local governments and to hundreds of articles and newscasts by trade and popular media. The perception is generally favorable although many

misconceptions still persist and most mass builders are still reluctant to use passive solar, not yet convinced that a sufficient market demand exists. Most designers still have limited experience and are frequently quite unsophisticated.

Only a handful of communities have adequate zoning for solar access.

Quantity of buildings. Quite understandably, passive solar has made the greatest penetration into new, custom, single-family housing although the diffusion into other segments is occurring at an increasing rate. The number of retrofit applications is comparable to new construction. Typically, passive solar catches on and spreads in a local area, often no larger than a single town or county and then diffuses outward. Thus we find pockets of passive solar in many parts of the country with vast areas in between virtually untouched. Where these pockets start is due more to the intrepidity of a few local people and a willingness to try something new than to the climate. The generally favorable performance of these initial buildings then leads quickly to more applications, to a diversity of building types, and to a sophisticated level of awareness among appraisers, lenders, and local officials.

Quality of buildings. The quality of passive solar buildings varies enormously. The best performers reduce energy use by a factor-of-ten in new construction (compared to conventional, temporary buildings) or a factor-of-four in retrofit also providing good comfort conditions and an attractive, livable environment. The poorer performers give little, if any, energy savings, are uncomfortable, or have other drawbacks. The general quality has not necessarily improved as applications have become more widespread. In part, this is due to many new designers entering the field and also due to a tendency on the part of some builders to employ "token passive solar," primarily to promote sales, rather than offer a well integrated design. The most frequent shortcomings are insufficient energy conservation and either shortcutting on thermal mass or poor relationship of mass to glass. There are few yardsticks prospective buyers can use to predict performance without each becoming knowledgeable in the nuances of passive solar design.

#### 2. Evaluation

Modeling and simulation. Performance can be accurately predicted by computer analysis for the

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standard passive solar configurations. Thermal network modeling is most commonly used but response factor and frequency domain solutions have also been successful. Most commonly used algorithms have been validated against test room or other experiments although few complex situations have been so tested (such as earth integration). The least validated areas are those involving natural convection between and around spaces, including the double-envelope configuration.

Performance measurement. Many dozens of small test rooms have been built in a variety of climates. Data have been used both for side-by-side comparisons and model validation. The test rooms are generally quite predictable and provide an inexpensive and effective means of testing concepts and as hands-on teaching tools.

Performance measurement of actual buildings lags seriously. Although excellent performance has been reported, only a handful of buildings have been monitored in sufficient detail to fully understand and document performance. The difficulty and cost of doing this well have generally been underestimated. In most other instances energy savings are well publicized but other concomitant performance measures, such as comfort achieved, are frequently not reported. The new Class A and Class B programs are an important advance but no data are yet available.

### 3. Design Aids

There is little agreement within the design community as to which types of design aids are most appropriate due to the diversity of designers, design approaches, and building types.

Rules of thumb and patterns have evolved for many basic situations but for more complex issues, such as heat distribution, there are few guidelines. Simplified methods of predicting energy savings due to solar, most notably the Solar Load Ratio (SLR) correlation method, have been developed for the basic configurations and are in wide use. Recent expansion of the basic six configurations to 94 reference designs adequately covers most common direct gain, thermal storage wall, and sunspace variations. A method of optimizing the mix of passive solar and energy conservation has been developed and has recently been reduced to a practical procedure. Some simplified methods for predicting thermal comfort have been developed but they are only applicable to the simplest configurations. Virtually no work has been done on the quantification of hybrid design approaches.

A handbook has been written which presents the SLR method as a very simple annual method and also as a monthly method and another handbook presents many useful passive solar construction details.

Programmable calculator and microcomputer based design aids have been developed commercially and are being marketed. They represent a huge step over the strictly manual methods in ease of use and speed. Many implement the SLR technique and others use more comprehensive approaches such as simulation to provide more information to the designer.

Simplified techniques are not so well developed for more complex buildings such as many commercial buildings with large internal gains or complex HVAC

interactions. The limits of the SLR method have not been well defined. The "energy graphics" method for time-of-day comparison of sources and losses has seen some use and has considerable potential to beneficially influence good design.

The compelling power of hour-by-hour computer-based performance estimation methods have led those developing design aids for larger commercial buildings to concentrate primarily on large codes. It is too early to tell how effective these will be as design aids or to what degree they will penetrate the design community.

An important aid to design is previous experience, yet designers have shown little tendency to learn from the past primarily due to lack of adequate post-occupancy evaluation of existing passive solar buildings.

### 4. Products and Materials

Many new specifically passive solar products have emerged and others have been adapted for passive solar application. These include movable insulation systems for windows, infrared-reflective glazings, window shades and blinds, and controls. Two large industries have recently realized the major importance that passive solar can play in their future and have developed major information programs to maximize the benefit to their members; these are the window industries and the masonry industries. This is an important development because simply through the manufacture and use of energy-effective window assemblies and the appropriate use of suitable masonry products, much of the potential of passive solar can be realized. Multiple function use of these elements is critical to achieving good economics.

Phase-change storage remains an ever-popular topic for research but few effective purely passive applications have been demonstrated. However, heat storage in water containers is in wide use and many new and effective methods of containment have been developed and marketed.

Selective surfaces have been demonstrated to be effective in thermal storage wall applications but there is some evidence that the full performance potential may not always be realized.

### NEEDED FUTURE RESEARCH ACTIVITIES

Researchers are just beginning to develop an understanding of energy flow in buildings. Continued work is needed to document the benefits or shortcomings of existing and new approaches and to provide techniques of accurate performance prediction. Many innovations that enhance comfort, reduce costs, and reduce energy consumption can be expected from future research.

Specific areas needing work include the following:

- Develop a thorough understanding of how absorbed solar heat is stored and released throughout a building. Important beginnings have been made but we are far from the complete quantification needed for developing of effective design patterns and performance prediction methods.

The solution in many of the first and second generation passive solar buildings has been thermal storage overkill. Extra mass was used liberally in every aspect of the construction to achieve great thermal stability. While this has usually been successful it has not often been the most economical approach. Mass added to buildings tends to be more expensive than frame construction and is particularly expensive to insulate adequately on exterior facades. If there is to be wide-scale acceptance by builders of passive solar design, either inexpensive mass must be employed (such as basement walls) or mass which is added must be used very judiciously. Its heat storage potential must be maximized and it should serve multiple functions.

- Develop a thorough understanding of natural convective mechanisms of heat distribution. In any but single-zone buildings this is critical if other than solar rooms are to benefit from passive solar gain.
- Continue performance evaluation of convective loop air heaters (which are particularly appropriate to retrofit applications) to optimize the design and provide for accurate performance prediction.
- Develop techniques for analyzing and optimizing the design of hybrid systems such as fan-forced rock beds and heat storage in basement walls, and also for active solar collector systems used in conjunction with passive designs.
- Expand the development of simplified performance prediction techniques to include thermal storage roofs, complex mixed systems, buildings with large internal gains, and multiple-zone configurations.
- Develop methods of accounting for ground coupling in passive solar buildings.
- Evaluate thermal storage wall and other purely passive applications of phase-change materials, particularly for retrofit applications.
- Pursue performance evaluation of various purely passive techniques of reducing energy losses from thermal storage walls such as selective surfaces, honeycombs, and other methods pioneered in solar collectors. The lower temperature environment should open up several avenues here.
- Continue work on effective and simple means of control, especially methods which allow occupants of specific single rooms (as in commercial buildings) a degree of control over their environment.
- Continue the investigation of methods which enhance the inherent off-peak character of backup heat demand in passive solar buildings.
- Quantify the summer cooling implications of passive solar heating approaches and develop techniques for global design optimization accounting for both summer and winter performance.

## JOINT INDUSTRY/GOVERNMENT ACTIVITIES

The following are areas appropriate for cooperative activities with industry:

- Develop and test improved glazing systems for increased solar transmittance, reduced heat losses, adequate summer ventilation, security, and simple control of each function.
- Develop and test movable insulation systems to be used outside of the window.
- Develop standard testing procedures for window and movable insulation assemblies which properly account for edge and air leakage effects.
- In conjunction with the masonry industries develop appropriate methods to quantify the effectiveness of masonry used in various ways as thermal storage (as a design aid).
- Develop less expensive methods of performance monitoring. Although the Class B system is well suited for its particular application, it is still too expensive and perhaps a little too sophisticated for widespread use. Evolving computer technology should provide new opportunities for simplifications and for cost reductions (perhaps in conjunction with a microprocessor system that performs other functions in the building).
- Develop a simple common basis for energy rating buildings (similar to EPA ratings for autos) to be applied to both new and retrofit situations.
- Develop standardized procedures for post-occupancy evaluation of passive buildings and dissemination of results. The new Class A monitoring system is an important beginning.
- In conjunction with design firms or professional societies, develop design aids suitable for use in large buildings.
- In conjunction with builders and utilities, develop and test methods of off-peak backup heating.

## CONCLUSION

Much has been accomplished but more remains to be done. In the past year or two a misconception has emerged that passive solar heating technology is fully developed and that no further research is warranted. However, a review reveals many gaps in both the technology and its practice. There are many outstanding examples of passive solar buildings of all types in all climates which meet or exceed performance expectations. But most builders and buyers are not yet convinced that passive solar is appropriate for them. Key factors which differentiate excellent performance from marginal performance are not fully understood. The field is not yet mature.